Communication Systems

WPAN: Bluetooth
Outline

• Historical perspective
• Piconet
• Scatternet
• Latency modes
• Applications
Bluetooth

Bluetooth (BT) wireless technology is a short-range communications system intended to replace the cable(s) connecting portable and/or fixed electronic devices. The key features of Bluetooth wireless technology are robustness, low power, and low cost.

The Bluetooth Special Interest Group (SIG) releases the BT specifications. In addition, The IEEE 802.15 Working Group for Wireless Personal Area Networks approved the WPAN standard derived from the BT specification.

Example: BT system can manage a number of low-cost point-to-point or point-to-multipoint links over a distance of 10 m with a transmit power less than 1 mW.
History

- 1994: Ericsson (Mattison/Haartsen), project
- Renaming of the project: Bluetooth according to Harald “Blåtand” Gormsen, King of Denmark in the 10th century
- 2001: first consumer products for mass market, spec. version 1.1 released
- November 2004: Version 2 released
- 1999: IEEE 802.15 WG was created to develop WPAN standard
  - March 2002 IEEE 802.15.1 has been released (= Bluetooth, without major changes)
  - 802.15.3 high speed WPAN, draft standard available, 11 – 55 Mbps
  - 802.15.4 low rate WPAN, for wireless sensor networks, 20 kbps – 250 kbps

Special Interest Group

- Original founding members: Ericsson, Intel, IBM, Nokia, Toshiba
- > 4000 members (February 2006), >7000 members (February 2007), >10000 (February 2008), >14.000 (February 2011)
- Any company incorporating Bluetooth wireless technology into products, using the technology to offer goods and services must become a member of Bluetooth SIG
- Common specification and certification of products
The rune stone is located in Jelling, Denmark, erected by King Harald “Blåtand” in memory of his parents. The stone has three sides – one side showing a picture of Christ.

Inscription:
"Harald king executes these sepulchral monuments after Gorm, his father and Thyra, his mother. The Harald who won the whole of Denmark and Norway and turned the Danes to Christianity."

1999: Ericsson mobile communications AB reste denna sten till minne av Harald Blåtand, som fick ge sitt namn åt en ny teknologi för trådlös, mobil kommunikation.
Unlicensed radio operation

• BT operates in the globally available unlicensed ISM (Industrial, Scientific, Medical) band at 2.4 GHz.

• Radios operating in the ISM band are required to apply spectrum-spreading techniques if their transmitted power levels exceed 0 dBm.

• BT applies per-packet frequency hopping for transmitting data over the air
  – Basic physical channel is defined by pseudorandom hoping over 79 RF channels, 1 MHz carrier spacing
  – Channel 0: 2402 MHz … channel 78: 2480 MHz
  – Frequency hopping with 1600 hops/s
**Piconet (1)**

- The units that share the same physical channel form a *piconet*
- One station has a role of a master, other act as slaves

- Each piconet may only contain 1 master and up to 7 simultaneous/active slaves (> 200 could be parked)
- 7 slaves → in order to keep high-capacity links between all the units + to limit the addressing overhead

- Master controls communication in a piconet.
  - Provides time- and hop-synchronization
  - No direct slave-to-slave radio links are possible.
**Piconet (2)**

- Each piconet has a unique hopping pattern
- Participation in a piconet = synchronization to hopping sequence
  - Master gives slaves its clock and device ID
    - Hopping pattern: determined by device ID (48 bit, unique worldwide)
    - Phase in hopping pattern determined by clock
    - Hopping sequence in a pseudo random fashion, determined by a master
- Addressing
  - Active Member Address (AMA, 3 bit)
  - Parked Member Address (PMA, 8 bit)
Communivation in a piconet

- Polling-based TDD packet transmission
  - 625µs slots, master polls slaves
- Master polls slaves according to a polling scheme.
- Slave transmits only after it has been polled. NULL packet
- Master schedules the traffic in both the uplink and downlink → completely contention-free access → intelligent scheduling algorithms are needed

Independent piconets can interfere when they occasionally use the same hop carrier ← «no listen-before-talk»
Link types

- SCO (Synchronous Connection Oriented) – Voice
  - Circuit-switched, periodic single slot packet assignment, 64 kbit/s full-duplex, point-to-point, symmetric, *no retransmission*
- ACL (Asynchronous ConnectionLess) – Data
  - Variable packet size (1,3,5 slots), asymmetric bandwidth, point-to-multipoint, ARQ protocol used
- eSCO (Enhanced SCO) – Streaming (v1.2)
  - Circuit-switched, symmetric or asymmetric, retransmission immediately after the reserved slots
Multislot packets

- 3-slot and 5-slot packets
- Multi-slot packets are sent on a single-hop carrier

![Diagram showing multislot packets]
Packet format for basic rate

- Access code
  - Channel, device access, e.g., derived from master

- Packet header
  - 1/3-FEC used, active member address (broadcast + 7 slaves), link type, alternating bit ARQ/SEQ, checksum
Types of packets

• 4 control packets
  – ID (identification packet) - used for signalling
  – NULL - consists of access code+header
  – POLL - used by a master to force a slave to return a response
  – FHS (FH synchronisation) - used to exchange clock and ID information between units

<table>
<thead>
<tr>
<th>Segment</th>
<th>TYPE code</th>
<th>Slot occupancy</th>
<th>SCO logical transport (1 Mbps)</th>
<th>eSCO logical transport (1 Mbps)</th>
<th>eSCO logical transport (2-3 Mbps)</th>
<th>ACL logical transport (1 Mbps) ppt=0</th>
<th>ACL logical transport (2-3 Mbps) ppt=1</th>
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### Throughput of different ACL packet types (kb/s)

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<th>Type</th>
<th>Payload Header (bytes)</th>
<th>User Payload (bytes)</th>
<th>FEC</th>
<th>CRC</th>
<th>Symmetric Max. Rate (kb/s)</th>
<th>Asymmetric Max. Rate (kb/s)</th>
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Retransmissions

- Retransmission
  - ACL only, fast ARQ
  - Restricted retransmission for eSCO
- Forward Error Correction
  - SCO and ACL

Error in payload (not header!)
Retransmission in eSCO

- The retransmission windows can be used for SCO retransmission (if there is error in the previous SCO transmission); otherwise, these slots can be used by typical ACL traffic.
Forming a scatternet

- A device can be a slave of multiple piconets, but master only in one
- Participation of a device in multiple piconets has to be on a time-division basis
Scatternet example

- Bluetooth network can be used to interconnect devices in a PAN
- Scatternet capability can be used to interconnect several PANs or to connect PANs to an Internet access point.
Scatternet functionality

- Scatternet offers a flexible way of creating BT networks
- Bluetooth networking functions fall into three main areas:
  - Scatternet formatting and maintenance
    - Must be able to adapt to connectivity, traffic, node mobility
    - Optimal → min delay / max throughput / min energy consumption
  - Scatternet-wide packet forwarding
  - Intra- and interpiconet scheduling
    - Master distributes capacity fairly or according to a weighted policy
    - Scheduling of a bridge should facilitate traffic flow between piconets
    - Intrapiconet scheduler should consider interpiconet scheduler
**Sniff mode**

- To reduce the duty cycle of the slave’s listen activity by only listening in specified slots
- Parameters of sniff mode are negotiated between master and slave
- Master can start transmission only in the sniff attempt interval
Hold mode

- Hold mode stops ACL traffic for a specified period of time; it does not affect SCO traffic
- Parameter hold time is negotiated. After hold time, slave «wakes up»
**Park mode**

- Slave gives up its AR_ADDR (3 bit), gets PM_ADDR (8 bit)
- Slaves wakes up periodically in predefined intervals to listen to the channel to synchronize and listen for broadcast messages
- Clock drift
Examples of usage of latency modes

- Sniff mode can be applied in scenarios with periodic traffic and is normally used to save power on low data rates.
- Hold mode can be used to perform another activity such as inquiry, page or scan operation/ or for participation in another piconet
- Park mode is generally used to handle more than 7 slaves in a piconet
Power classes of BT devices

- Power Class 1: is designed for long range (~100m) devices, with a max output power of 20 dBm,
- Power Class 2: for ordinary range devices (~10m) devices, with a max output power of 4 dBm,
- Power Class 3: for short range devices (~10cm) devices, with a max output power of 0 dBm.

- Power control: Each device can optionally vary its transmitted power. Equipment with power control capability optimizes the output power by measuring RSSI and reporting back if the power should be increased or decreased.
Bluetooth - Open issues

• Ad-hoc networking
  – Topology creation and maintenance

• Traffic engineering
  – Efficient inter-piconet communication
  – Routing in Bluetooth scatternets
Self-interference in Bluetooth

![Graphs showing symmetric and asymmetric data packet collision rates vs number of piconets for different slot transmissions.]
User scenario

- Wireless office (mouse, keyboard, printer)
- Hands-free headset for a mobile
- Sending small advertisements to discoverable, Bluetooth devices
- for game wireless controllers
- Short range transmission of health sensor data to dedicated medical devices
- Support for ad hoc networking
  - Interactive conference – connect every participant for instant data exchange
- Three-in-one phone – use the same phone everywhere (Allowing a DECT phone to ring and answer calls on behalf of a nearby cell phone)
- Real-time location systems (RTLS), are used to track and identify the location of objects
- Aalborg Zoo; airports etc
- ? Sensor networks
Literature